# Chapter 3
# Groins

## 3-1. Objective

The objective of constructing a groin or groin system is to stabilize a stretch of beach against erosion where that erosion is due primarily to a net alongshore loss of sand. The beach may be either natural or artificially nourished. It may be intended for protection or for recreation; thus, groins can serve to protect an area or to maintain a wide recreational beach. Groins are narrow structures, often of rubble-mound or sheet-pile construction, that are usually built perpendicular to the shoreline. Groins may be used to build or widen a beach by trapping longshore drift, stabilize a beach that is subject to severe storms or to excessive seasonal shoreline recession by reducing the rate of sand loss by longshore transport, reduce the rate of longshore transport out of an area by locally reorienting the shoreline so that it is more nearly parallel with the predominant incoming wave crests, reduce longshore losses of sand from an area by compartmenting the beach, and prevent sedimentation or accretion in a downcoast area (i.e., inlet) by acting as a barrier to longshore transport.

## 3-2. Functional Design.

*a. General.* Functional design refers to determining whether groins can provide an acceptable solution to a beach erosion control problem. It involves determining the limits of a project area as well as the layout and dimensions of a groin or groin system to meet project objectives that may be to provide a protective beach or recreational beach with specified dimensions. It involves evaluating preproject conditions along a beach, estimating the effect of groin construction, and determining whether the amount of sand in longshore transport is sufficient to maintain project dimensions or whether it must be supplemented by beach fill. The frequency of nourishment must also be established.

*b. Sediment budget.* Functional design of groins requires knowledge of the sediment budget and longshore sand transport environment at a project site. Groins might be considered if the net sediment loss from a project area is by longshore transport, that is, if the amount of sand leaving the project area by longshore transport exceeds the amount entering. Groins may retain sand within a project area and reduce or stop sand loss to the downcoast area. Groin construction brings about changes in an area's sediment budget. These changes can be temporary or permanent depending on the type of groins, their dimensions, how permeable they are to sand, and whether beach fill is included in the project. The postproject sediment budget basically states that the rate of natural supply of sand entering the project area following groin construction, plus any beach nourishment, less the rate of sand loss from the area, equals the rate of accretion (or erosion) of sand in the project area. The estimated erosion rate will establish the required frequency for periodic nourishment. Note that the sediment budget for an area is dynamic, responding to daily and seasonal changes in waves, currents, etc. Therefore, a sediment budget based on long-term averages will not reflect these seasonal variations in transport conditions. Unfortunately, data are rarely available to do anything but a long-term sediment budget. A postproject sediment budget should also be developed for areas immediately downcoast and upcoast of a groin system to establish the extent of any sand deficit or shoaling problems caused by the groins. These sediment budgets can determine the extent of beach nourishment to include as part of a beach-fill project.

*c. Types of groins.*

(1) Groins, like beach stabilization structures in general, may be classified in several different ways. For example, they can be classified by the type of construction and by the materials of which they are built. Groins are routinely constructed of sheet piling, either as a single row of timber or steel piling with walers and adjacent piles for lateral support or as sand and stone-filled steel sheet-pile cells. At exposed ocean sites, groins are most often of rubble-mound construction because of the ability of rubble-mound structures to withstand wave conditions exceeding original design levels while continuing to function, their relatively low wave reflection coefficients, and the apparent ability of rubble-mound groins to reduce the chance of rip current formation. Sheet-pile groins are often provided with rubble-mound heads, that portion of the groin in deepest water and thus subjected to the highest waves, and they are often flanked with rubble to reduce reflections, minimize the formation of rip currents, and protect against scour with its resulting reduction in the groin's lateral structural stability.

(2) Groins are normally straight and perpendicular to the preproject shoreline; however, they are occasionally curved, hooked, or have a shore-parallel T-head at their seaward end. Occasionally, shore-parallel spurs are provided to shelter a stretch of beach or to reduce the possibility of offshore sand transport by rip currents. These latter refinements are generally not deemed effective in improving a groin's performance. They simply add to the

cost. The least amount of construction materials and the shortest groin length are obtained by a straight, shore-perpendicular structure. If T-heads are deemed necessary, shore-parallel, nearshore breakwaters should be considered as an alternative that eliminates the shore-connecting groin structure and thus reduces the volume of construction materials needed.

(3) Groins can be classified as either "long" or "short," depending on how far across the surf zone they extend. Groins that traverse the entire surf zone are considered "long," whereas those that extend only part way across the surf zone are considered "short." These terms are relative since the width of the surf zone varies with the prevailing wave height and beach slope. During periods of low waves, a groin might function as a "long" groin, whereas during storms it might be "short." Groins can also be classified as either "high" or "low," depending on how high their crest is relative to prevailing beach berm levels. "High" groins have crest elevations above the normal high-tide level and above the limit of wave runup on the beach. There is little wave energy transmitted over a high groin, and no sediment is transported over them on the beach face. "Low" groins have crest elevations below the normal high-tide level, and some sediment can be transported over the groin on the beach face. "Permeable" groins allow sediment to be transported through the structure; "impermeable" groins are sand tight. Most sheet-pile groins are impermeable. Some level of permeability, if desired, can be obtained with rubble-mound groins by adjusting the size of the stone and the cross-section design. Several patented precast concrete groin systems are designed to be permeable.

*d. Siting.*

(1) Length of shoreline to be protected is a consideration in siting the groin. The effect of a single groin on beach accretion and erosion extends some distance upcoast and downcoast from the groin. For a system of groins, the effect extends upcoast of the most updrift groin and downcoast of the most downdrift groin. The effect depends on groin length and probably extends some tens of groin lengths from the groin. The reach of shoreline stabilized by a groin system will depend on groin spacing, which in turn depends on groin length and prevailing longshore transport conditions. Groin length, in turn, is selected based on the width of the surf zone and on the amount of longshore transport the groin should impound. Protection will extend upcoast of the updrift groin; the distance it extends will depend on the wave environment. For areas where waves approach nearly perpendicular to shore, the distance updrift is greater than for areas where waves approach at a greater angle. (However, the time to impound sand is much greater owing to the lower longshore transport rates that prevail under nearly shore-parallel waves.) Similarly, the potential for significant erosion extends farther downcoast of the most downdrift groin. In areas where the direction of transport periodically reverses, the area of downcoast erosion may move from one end of the project to the other; however, because of the time required for erosion to occur, the severity of the erosion may not be as great under conditions of varying transport direction. The best way to establish the range of influence of a groin is to observe the effect of nearby groins or other longshore transport barriers on the beach. The beach alignment upcoast of a proposed groin should approximate the beach alignment upcoast of an existing transport barrier since the shoreline generally aligns itself parallel to incident wave crests characteristic of antecedent wave conditions. Thus if an existing groin or barrier is to be used to estimate the expected shoreline alignment, it should be observed over a period of time and during all seasons of the year to determine the range of possible alignments.

(2) Sand in the fillet updrift of a groin requires time to accumulate, particularly if the groin is filling by natural processes. Likewise, time is required for any downcoast erosion to occur. The amount of accumulation and erosion are greatest close to the groin and diminish with distance from the groin. The groin’s effects propagate upcoast and downcoast from the groin. The rate of accumulation and erosion depends on the net rate of longshore transport. In areas where net longshore transport is high or in areas of nearly unidirectional transport, rates of accumulation and erosion will be high.

(3) Because of the potential for erosion along beaches downdrift from a groin system, a transition section composed of progressively shorter groins may be provided to prevent the formation of an area of severe erosion.

(4) Recent advances in the numerical computer simulation of shoreline evolution in the vicinity of coastal structures can be used to approximate the performance of a groin or groin system if the wave environment, including wave direction, is known (LeMéhauté and Soldate 1980, Perlin and Dean 1979, Kraus 1983, Hansen and Kraus 1989). Such models can be used to estimate the shoreline configuration as a function of time both upcoast and downcoast of a groin or groin system.

*e. Groin length.*

(1) Groins function by interrupting the longshore sand transport. Most longshore transport takes place in the surf zone near shore between the outermost breaking waves and the shoreline and also on the beach face below the limit of wave runup. Consequently, groin length should be established based on the expected surf zone width with the shoreline at its desired postconstruction location. Groins that initially extend beyond this point will impound more sand than desired, and the shoreline at the groin will accrete until sand eventually begins to pass around its seaward end. The sand fillet accumulated by the groin will then extend farther upcoast than desired (more sand will be impounded), and erosion will extend farther downcoast (a greater sand deficit will exist along downcoast beaches). Groins that do not extend across the entire surf zone will not intercept all of the longshore transport. Some sand will bypass the groin's outer end immediately following construction. This sand bypassing of the structure may be desirable to minimize erosion along downdrift beaches.

(2) The location of the surf zone varies with wave height and tidal stage; therefore, the relative groin length also changes with wave and tide conditions. Nearshore wave breaking occurs when a shoaling wave's height increases until the wave-height-to-water-depth ratio exceeds about 0.5 to 0.78; thus, higher incident waves break in deeper water farther from shore, the surf zone is wider, and the relative groin length is shorter. Similarly, at high tide incident waves of a given height will break closer to shore. Thus, at high tide the groin will be relatively longer.

(3) The SPM (1984) provides guidelines for estimating the trapping efficiency of groins (the fraction of the longshore transport trapped) depending on the water depth in which they terminate. These are estimates for the Atlantic coast with an average water depth at breaking of 1.8 meters. For long, high groins extending to -3.0 meters MLW (or Mean Lower Low Water, MLLW), 100 percent of the longshore transport is trapped. For high groins extending to between -1.2 and -3.0 meters MLW (or MLLW) or for low groins extending to less than -3.0 meters MLW (or MLLW), 75 percent of the longshore transport is trapped. For high groins extending to -1.2 meters MLW (or MLLW), 50 percent of the longshore transport is trapped. These are estimates of the equilibrium trapping/bypassing values that will prevail when the groin fillets are full.

*f. Groin height and crest profile.* Selection of a groin's height is based on several factors which will minimize the amount of construction materials used, control sand movement over the top of the groin, control wave reflections, and control the amount of sheltering from waves the groin provides to nearby downdrift beaches. Generally, a groin profile should have three sections: a high landward end with a horizontal crest at about the elevation of the existing or desired beach berm, a seaward sloping section that connects the high landward end with an outer or seaward section at about the slope of the beach face, and a seaward section generally with a lower elevation (Figure 3-1). However, most groins have been built with a constant crest elevation along their entire length, which causes increased offshore losses rather than allowing transport over the groin. The landward and sloping sections are intended to function as a beach template against which sand can accumulate on the updrift side of the groin. The groin profile is built to approximately the desired postproject beach profile. The seaward section is intended simply to prevent longshore sand movement in the surf zone. A higher seaward section shelters a portion of the downdrift beach and displaces any erosion problem farther downcoast. A lower seaward section will allow waves to carry some sediment over the structure and will reduce wave reflections from the groin. A significant amount of sand is transported on the beach face in the swash zone (Weggel and Vitale 1985); consequently, the amount of sand passing over a groin when it is full (overpassing) is determined by the elevations of the sloping and seaward sections.

*g. Groin Spacing.*

(1) The spacing of groins along a beach in a groin system is generally given in terms relative to the length of individual groins. The distance between groins is usually on the order of two to three groin lengths where groin length is specified as the distance from the beach berm crest to the groin's seaward end. Groin spacing should be selected by an analysis of the shoreline alignment that is expected to result following groin construction. Shoreline alignment is in turn a function of the wave and longshore transport environment at a site. It depends primarily on the prevailing direction of incident waves. When incident wave crests are nearly shore-parallel, a larger groin spacing can be used; when incident wave crests make a large angle with the shoreline, closer groin spacing is required. (When wave crests are nearly shore-parallel, longshore transport rates are small, and groins may not provide a satisfactory solution to an erosion problem.)

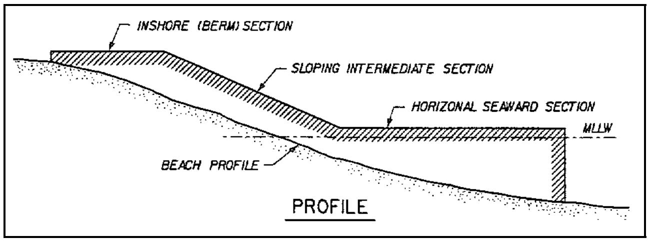


**Figure 3-1. Typical groin profile showing inshore (berm) section, sloping intermediate section, and horizontal seaward section**

For a specified direction of wave approach, optimum groin spacing can be determined by redistributing the sand within a groin compartment so that the shoreline is aligned parallel with the incoming waves. The quantity of sand contained within a groin compartment is assumed constant, and shoreline accretion at the downdrift end of the compartment is balanced by shoreline recession at the updrift end. If the project includes beach nourishment, the volume of beach-fill sand is included in the sediment balance. Similar calculations can be performed for various directions of wave approach to obtain insight into possible shoreline fluctuations due to seasonal changes in wave conditions. Details of computing the sediment balance within a groin compartment are summarized in the SPM (1984, Chapter VI, Section 3).

(2) When wave direction and transport rates are variable, the shoreline alignment near groins will also vary. Numerical computer models of shoreline response to groin construction in an environment of changing transport directions and rates can provide insight into how the shoreline will behave and the range of possible shoreline configurations that will result. Different groin spacings can be investigated for a given wave environment and the groin spacing that provides an optimum shoreline response selected.

*h. Permeability.*

(1) General.

(a) Permeability refers to the transport of sand through a groin; a permeable groin is one that will allow some sand to pass through it. Usually, sheet-pile groins are impermeable while rubble-mound groins will have some degree of permeability unless special precautions are taken to ensure that the groin is sand tight. Permeability may be desirable if some sand is to be bypassed to downdrift areas. There are no quantitative guidelines for determining the permeability to sand of a given groin geometry. Low rubble-mound groins have been used as terminal structures that allow controlled sand losses from a beach erosion control project to preclude erosion along adjacent beaches. The permeability of rubble-mound structures can be adjusted by adding or removing stone and by raising or lowering their crest elevation where it intersects the shoreface. A "vertical" barrier of geotextile fabric through the interior of the structure can reduce sand passage. However, this is a trial and error procedure, and actual permeability varies with water level and wave conditions.

(b) Several patented precast concrete groin systems are permeable, and some allow their sand bypassing to be adjusted. However, experience with these systems has been too limited to quantitatively predict their sand bypassing ability.

(2) Void sealing to reduce permeability.

(a) Occasionally rubble-mound terminal groins, jetties, or breakwaters are too permeable and allow sand and/or wave energy to pass through them. For example, a terminal groin may allow too much sand to leave a beach-fill project area; a jetty may allow sand to move through it from an adjacent beach into a navigation channel, or the voids in a breakwater may allow wave energy to be transmitted through it. Occasionally, voids exist due to design or construction deficiencies, but most often, voids develop or open in rubble-mound structures due to the loss of core stone resulting from storm wave action or due to structural settlement. Thus, many older structures may not function as intended because of an increase in their permeability.

(b) If the function of a structure is seriously impaired by its permeability, steps to seal the voids may be economically justified. The quantity of sand passing through the structure and the cost of dealing with it determines if void sealing is warranted. The first step is to determine whether sand is in fact passing through the structure or whether it is passing over or around the structure. This problem can often be identified by a study where dye is injected into the water updrift of a structure and signs of the dye are sought downdrift of the structure. Wave setup on one side of the structure creates a hydraulic gradient that causes a flow that in turn carries sand through the structure. If permeability is a problem, the dye appears downdrift within minutes of its updrift injection.

(c) Sealing voids in rubble-mound groins and jetties is discussed by Denes et al. (1990). Considerations include evaluation of materials used to seal voids, evaluation of how the sealant is to be installed, environmental impacts of introducing sealant materials into the marine environment, and the long-term durability of the sealants. Void sealants include grouts, stiff aggregate-containing cements, and asphalt. Denes et al. (1990) investigated two cementious mixtures, a sodium silicate-cement mixture, a sodium silicate-diacetin mixture, and a sand-asphalt mixture. The cementious mixtures and the sand-asphalt mixture always hardened well whereas some problems were experienced with gelling of the sodium silicate mixtures and with their subsequent erosion and deterioration. To ensure a successful sealing project, Denes et al. (1990) recommend that a reliable, experienced contractor be employed; there be thorough inspection of the work while it is in progress to ensure that the structure is being adequately sealed; the job be evaluated while sealing progresses so that adjustments can be made as needed; and proper attention be given to spacing the injection boreholes to ensure an adequate distribution of the sealant. Rosati and Denes (1990) discuss a field evaluation of the rehabilitation of the south jetty at Port Everglades, Florida.

*i. Shoreline orientation and its effect on longshore transport.* Groin construction will result in the shoreline reorienting itself more nearly parallel with the prevailing incident wave crests. Following groin construction, the general shoreline alignment will be different than it was before construction. Net longshore sand transport rates along the reoriented shoreline will be lower because the angle between the average incoming wave crests and the new shoreline will be smaller. In other words, the shoreline will align itself so that positive and negative transport rates are more nearly balanced, thus yielding a lower net transport. If a time series of wave data are available, such as WIS hindcasts, the reduction in net transport can be estimated by calculating new transport rates for both the original shoreline and for the reoriented shoreline.

*j. Terminal groins.*

(1) The ends of beach nourishment/beach stabilization projects, where the project area abuts an adjacent inlet or a beach that is outside of the project area, require special attention. Significant amounts of sand can be lost from the project along with the associated economic benefits, or erosion can occur along sand-starved downdrift beaches. Terminal groins are constructed at the ends of beach nourishment projects to contain sand within the project area or to control the rate at which sand is lost from the project area by longshore transport. At inlets, sand lost from a beach nourishment project not only reduces the beach nourishment benefits, but it may also cause sedimentation and associated navigation problems within the inlet; consequently, a sand-tight terminal groin is necessary. Where nourishment projects abut beach areas, terminal groins that allow some sand bypassing may be needed to preclude erosion along adjacent beaches.

(2) Sand-tight terminal groins must be impermeable and are usually high and long in order to prevent sand from being carried through, over, or around them. Sand-tight rubble-mound terminal groins have an impermeable core usually of small, quarry-run stone or, in some cases, a sheet-pile cut-off wall. It is important to ensure that the design and subsequent construction assure a sand-tight groin since sealing the voids of an existing rubble-mound structure is expensive.

(3) Terminal groins designed to permit some sand bypassing are usually low, short, and permeable to sand. The amount of bypassing a given groin will allow is difficult to estimate; however, some guidance on transport over low groins and jetties is given in Weggel and Vitale (1985). Transport around the end of a groin can be estimated knowing the groin's length, the wave and longshore transport environment, and the cross-shore distribution of longshore transport. Hanson and Kraus (1989) discuss assumptions regarding bypassing around groins as related to the numerical model GENESIS. In general, longshore transport extends from the beach seaward to a water depth about 1.6 times the breaking depth of the transformed significant wave (Hallermeier 1983).

*k. Groin system transitions.*

(1) At the end of beach stabilization projects that employ groins and where the potential exists to erode downdrift beaches, a transition reach is often needed to go from the reach stabilized by groins to the adjacent unstabilized reach. The length of the groins at the end of the project is gradually decreased to form a transition from the project's typical groins to the adjacent beach (Figure 3-2). Generally, the groin shortening is effected along a line converging to the shore from the last full-length groin, making an angle of about 6 degrees with the natural shore alignment (Bruun 1952; USAED, Wilmington). The length of a groin is defined here as the distance from the bermline to the seaward end of the groin. The spacing between groins in the transition reach is also decreased to maintain a constant spacing-to-groin length ratio, *R*. The length of the first groin in the transition section is given by,

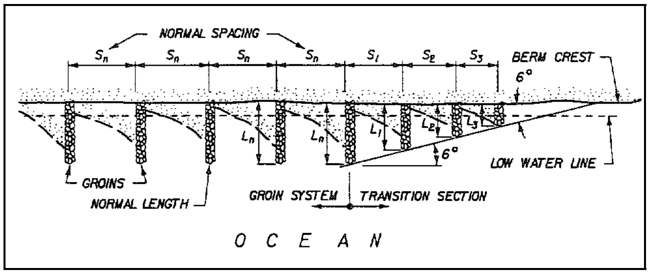


**Figure 3-2. Transition section between groin field and beach not stabilized by groins**

$$L_1 = \left[ \frac{1 - \left(\frac{R}{2}\right) \tan 6°}{1 + \left(\frac{R}{2}\right) \tan 6°} \right] L_n \qquad (3\text{-}1)$$

where

$L_1$ = length of the first groin in the transition
$R$ = ratio of groin spacing to groin length in the groin field
$L_n$ = length of the groins in the groin field

The spacing between the last groin in the groin field and the first groin in the transition section is given by:

$$S_1 = \left[ \frac{R}{1 + \left(\frac{R}{2}\right) \tan 6°} \right] L_n \qquad (3\text{-}2)$$

where

$S_1$ = spacing between the groins

(2) These equations can be used recursively to calculate the length of each succeeding shorter groin in the transition and its distance alongshore from the preceding groin. Thus $L_2 = C_o L_1$, $L_2 = C_o L_2$, etc. Also, $S_2 = C_1 L_1$, $S_3 = C_1 L_2$, etc., where $C_o$ and $C_1$ are given by the terms in brackets in Equations 3-1 and 3-2, respectively. $C_o$ and $C_1$ are each constant for a given $R$. The shortest groin in the transition should extend seaward to at least the mean lower low water line. Groin system transitions can also be investigated using the numerical model GENESIS (Hanson and Kraus 1989).

*l. Design to meet functional objectives.* The functional design of groins is discussed in detail in the SPM (1984), Chapter 5, Section VI. Several rules of groin design are repeated here.

(1) Rule 1: Groins can be used only to interrupt longshore transport. Groins are ineffective in preventing the loss of sand by offshore transport. The normal onshore-offshore transport of sand is essentially unchanged by the presence of groins. Longshore transport, however, is trapped by groins until the shoreline builds seaward to the point where sand can move around the groin's end, or the groin's crest elevation is such that sand can move over it during periods of high water.

(2) Rule 2: The beach adjustment near groins depends on the magnitude and direction of the longshore transport. Groins reorient the shoreline so that it is more nearly parallel with the prevailing incoming wave crests. If the direction of the incoming waves changes, the shoreline will move to reorient itself parallel with the new wave direction. The shoreline thus reflects the wave conditions that prevailed for some time prior to the time when the shoreline was observed. For example, if transport is to the south, the beach will build up against the northerly side of a groin; if transport is to the north, the shoreline will shift so that the buildup is against the southerly side of the groin.

(3) Rule 3: The groin-induced accumulation of longshore drift on the foreshore modifies the beach profile, which then tries to reestablish its natural shape. The beach profile along the updrift side of a groin will be steeper than the profile along the downdrift side. At the seaward end of the groin, the updrift profile elevation and the downdrift profile elevation must be essentially the same and, since the distance from the seaward end of the groin to the beach berm along the updrift profile is shorter, the average slope along the updrift profile must be steeper than the average slope along the downdrift profile.

(4) Rule 4: Water pushed by waves into a groin compartment sometimes returns offshore in the form of rip currents along the sides of groins. Since groins cannot prevent offshore losses, rip currents induced by groins often carry large quantities of sand seaward. There are three mechanisms (Dean 1978) that can cause rip currents to develop adjacent to groins: the groin deflects the shore-parallel longshore current seaward; wave setup adjacent to a groin causes an increase in the mean water level there while the portion of the beach sheltered by the updrift groin has lower waves, resulting in a circulation

cell within the groin compartment that flows seaward along the updrift groin; and differential waves setup along the shoreline between two groins when waves approaching perpendicular to the beach cause two circulation cells with rip currents flowing seaward along each groin.

(5) Rule 5: The percentage of the longshore transport that bypasses a groin depends on groin dimensions, fillet dimensions, water level, and wave climate. Sand passes around the ends of relatively short groins, i.e., groins that do not extend beyond the seaward end of the normal surf zone. Sand passes through rubble-mound groins having large voids that make them permeable. Sand in suspension passes over low groins. Sand will also pass over a groin on the beachface between the water line and the limit of wave uprush if the beachface is above the groin's crest elevation.

(6) Rule 6: The longshore drift that is collected in the updrift fillet is prevented from reaching the downdrift area, where the sand balance is upset. Sand trapped and retained on the updrift side of a groin is sand that would normally nourish the downdrift beach. Preventing this sand from reaching the downdrift beach causes a sand deficit there.

(7) Rule 7: In the absence of other criteria or if the spacing determined by the shoreline analysis appears to be unreasonable, the spacing between groins should equal two to three times the groin length as measured from the berm crest to the groin's seaward end.

(a) Spacing between groins should be determined by a shoreline orientation analysis. The shoreline between groins is determined by the predominant direction of wave approach. As numerical models evolve, groin spacing will be determined by the computed shoreline response to a simulated wave and long-shore transport environment deemed typical of the groin site. In the absence of such a numerical simulation, the "rule of thumb" spacing given by Rule 7 should be used.

(b) Dimensional analysis. A dimensional analysis of the variables important in groin design can provide insight into the factors governing the functional design of groins. Details on dimensional analysis and an example application can be found in Appendix C.

## 3-3. Structural Design.

*a. Loading*

(1) Wave forces.

(a) Because groins are oriented nearly perpendicular to the shoreline, waves propagate along the groin's axis so that their crests almost make a 90-degree angle with the groin. For sheet-pile groins, lateral wave forces arise because a wave crest acts on one side of the groin whereas a lower water level acts on the other, e.g., either the still-water level or a wave trough. For directions of wave approach that make a small angle with the groin axis, Mach-stem wave reflection occurs (Figure 3-3). The incoming wave crest aligns itself perpendicular to the groin's axis, and the resulting wave height acting on the groin is higher than, but not twice as high as, the incoming wave (Figures 3-4 and 3-5). Wave heights on the leeward side of the groin may be lower. However, the groin should be designed for waves approaching from either direction. Wave loading on vertical sheet-pile groins and jetties is discussed in Weggel (1981). The loading procedure was verified in the laboratory by Hanson (1982) and is based on the Miche-Rundgren non-breaking wave force diagrams in the SPM (1984, Chapter 7, Section 2). The force is distributed along the structure in proportion to the wave profile, and the wave profile is that of a conoidal wave. Figure 3-5 shows the reflection coefficient, and Figure 3-6 gives an example wave loading diagram. The maximum lateral force acts over only a portion of the structure at one time (at the location of the wave crest), and forces are distributed longitudinally along the groin by the walers.

(b) Most rubble-mound groins are designed with quarrystone armor heavy enough to be stable under a selected design wave height. A typical rubble-mound groin cross section is shown in Figure 3-7. Stone in the first underlayer is selected to be large enough so it will not fit through the voids of the armor layer; stone in the second underlayer will not fit through the voids of the first underlayer, etc. This criterion is met if the first underlayer weighs $W/10$ where $W$ is the median weight of the armor stone. This criterion assumes that the stone in the underlayers has approximately the same unit weight as the armor stone. By this criterion, the second underlayer

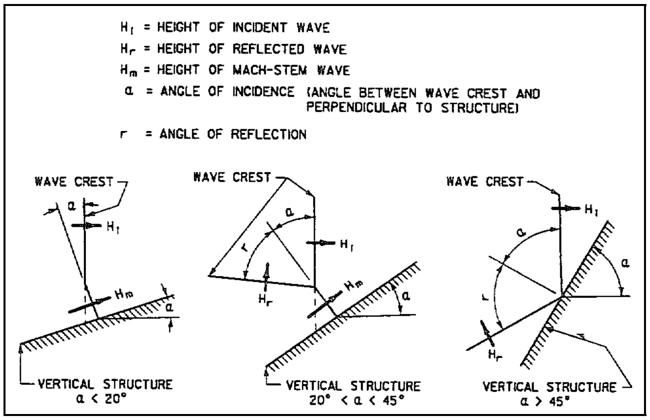


**Figure 3-3. Reflection patterns of a solitary wave, oblique angle of incidence (Perroud 1957)**

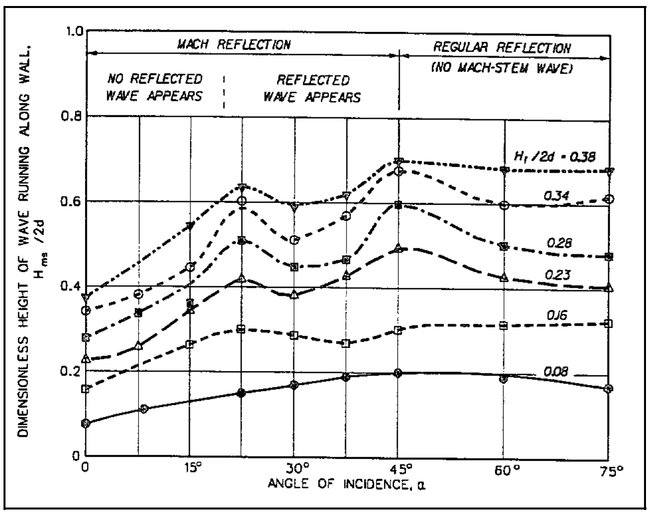


**Figure 3-4. Oblique reflection of a solitary wave, Mach-stem reflection (Perroid 1957)**

stone should weigh approximately *W*/100. The relationship between armor unit weight and design wave height is the same as that for jetties and breakwaters. More detailed information regarding the design of rubble-mound structures including groins is given in EM 1110-2-2904 and the SPM (1984, Chapter 7, Section III).

(c) Sheet-pile groins are often provided with rubble toe protection that serves as a scour blanket to prevent undermining and thereby a reduction in lateral stability. The stone weight needed for stable toe protection can be determined from EM 1110-2-1614 and the SPM (1984).

(2) Current forces.

(a) Currents can exert forces on both sheet-pile and rubble-mound groins; current caused forces, however, are usually small when compared with the forces due to waves. On sheet-pile groins, forces may result from the longshore current's impingement on the groin or from seaward flowing rip currents along the groin itself. Rip currents can cause an additional lateral force (along the axis of the groin) on a groin's lateral support piling.

(b) Current forces also act on rubble-mound groins both as longshore currents flowing over low groins and as seaward flowing rip currents along a groin's flank. Normally the stone weight necessary for stability against currents will be much less than the stone weight necessary for stability against wave action. Appendix IV of EM 1110-2-1601 discusses current forces on rubble and riprap bank protection.

(3) Earth forces. In addition to wave forces, forces due to the buildup of sediment and difference in sand elevation from one side of a sheet-pile groin to the other are important. The resulting earth forces coupled with wave forces establish maximum lateral forces and maximum bending stresses in cantilevered sheet-pile groins. Generally, the maximum sand elevation difference results in the maximum lateral force per unit groin length. The lateral earth force is due to a combination of both active and passive earth pressures acting on the updrift and downdrift sides of a groin. Active earth pressure occurs when there is a rotation or deflection of the pile groin. Active earth pressure acts in the direction of the deflection. Passive earth pressure develops to resist deflection of the groin and acts opposite to the direction of the deflection. The design of cantilevered sheet-pile walls is discussed in most texts on soil mechanics such as Hough (1957) and Terzaghi and Peck (1967). Also see EM 1110-2-2502, which discusses the design of vertical retaining walls. Earth retaining walls experience similar forces.

(4) Ice forces.

(a) Except for the Great Lakes, Alaska, and other freshwater bodies in northern latitudes, ice forces on groins are not important. On the Great Lakes and other freshwater bodies, however, horizontal ice forces on groins can result from a crushing and/or bending ice

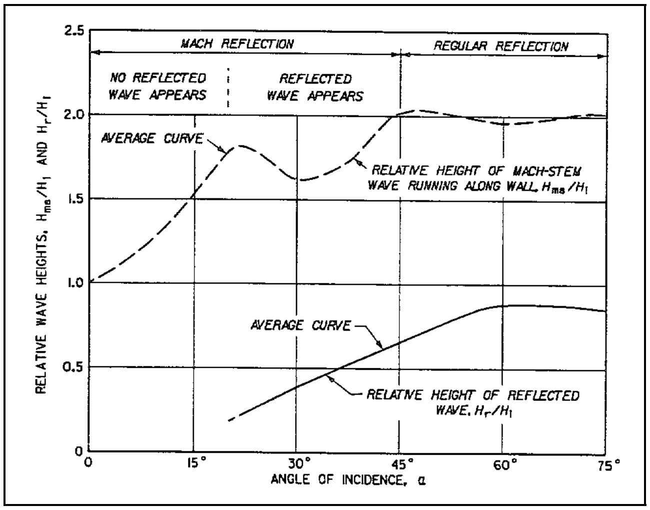


**Figure 3-5. Reflection coefficient for Mach-stem reflection of solitary wave (Perroud 1957)**

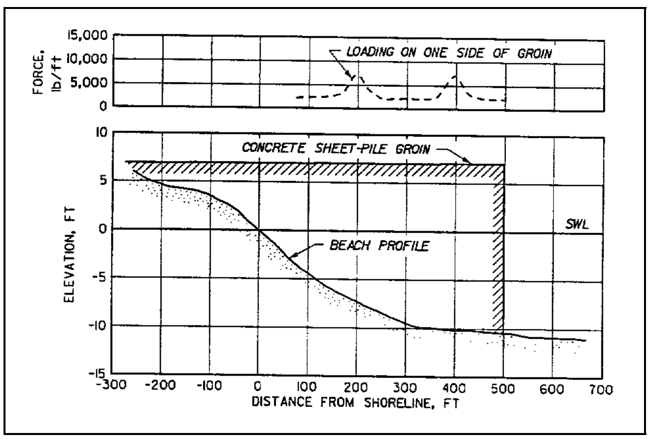


**Figure 3-6. Loading diagram, cnoidal waves running along a cantilevered sheet-pile groin (Weggel 1981)**

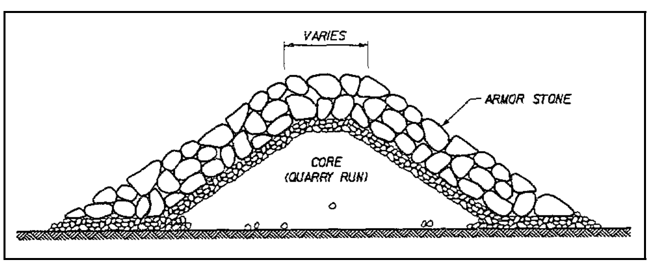


**Figure 3-7. Typical cross section of a rubble-mound groin**

failure of laterally moving ice sheets, impact by large floating ice masses, and by plucking forces on riprap and rubble. Vertical forces arise because of the weight of ice frozen on structures following lowering of the water level or due to water spray, and buoyant uplift forces due to an increase in water level. Fortunately, maximum ice and wave forces do not usually occur at the same time since ice shelters a structure from wave action.

(b) For groins closely spaced along a shore or closely spaced structural elements on a single groin, the expansion of a large ice sheet due to a temperature increase can lead to forces and deflections. The SPM (1984, Chapter 7, Section VI) and EM 1110-2-1612 provide information on the physical characteristics of ice and potential ice forces.

(5) Other forces.

(a) Other forces a groin might experience include impact forces due to wave-carried debris and small craft collisions. The magnitude of these forces is difficult to predict because the cause of the impact and the mass of the impacting body are not known a priori. If debris is suspected to be a problem, appropriate levels of conservatism should be included in the design.

(b) A groin may have to be designed to withstand forces that might occur only during construction; e.g., the groin may have to carry construction equipment or there may be surcharge due to temporary fill. These forces may be critical and exceed forces due to other more routine causes such as waves and currents.

b. *Structural analysis.*

(1) Fatigue. Wave action on sheet-pile groins located in coastal regions produce unique cyclic loading conditions relative to conventional vertical retaining walls on inland waterway systems. The stress range and number of cycles produced by the waves along with any unique framing conditions should be considered in the structural design of a groin. Fatigue considerations are discussed in the ASCI Steel Construction manual, *Allowable Stress Design* (1989).

(2) Fracture. Steel sheet piles used for groins may have high carbon equivalents and transition temperatures below the ambient project temperature. Consequently, the possibility of brittle fracture and stress corrosion cracking

should be considered in the structural design. Fracture considerations are discussed in Barsom and Rolfe (1987).

## 3-4. Design Process.

*a. Prototype examples.*

(1) One of the best predictors of a planned groin's performance is the performance of existing nearby groins or groins in similar wave and longshore transport environments. They can provide both functional and structural performance data. Nearby groins are usually sited in essentially the same wave and longshore transport environment and are acted upon by essentially the same forces. Shoreline response can be expected to be similar, with appropriate adjustments due to differences in exposure and shoreline alignment.

(2) Functional performance can be judged by observing the shoreline updrift and downdrift of an existing groin to determine the postconstruction shoreline that might be expected. Similarly, seasonal changes in shoreline alignment can be assessed. Care should be exercised, however, in extrapolating the observed behavior of a single isolated groin to the behavior of groins in a groin field. For the former, a long updrift beach can provide a source of sand, and the updrift fillet will continue to build, whereas for the latter, the sand supply is limited by the amount of sand within the groin compartment. In this case, the shoreline response will be more rapid. Even though the rate of response will be faster for the groin compartment, the general shoreline alignment should be about the same. If the rates of updrift accumulation and downdrift erosion at an existing groin have been monitored, information on longshore sand transport rates can be obtained, which in turn can be used to predict the rate at which the groins will fill.

(3) If a groin field is under construction, the sequence of construction is important, especially if beach fill is not a part of the project and the groins are expected to fill by natural longshore transport. The downdrift groin should be constructed first and allowed to fill before the next updrift groin is constructed; i.e., construction should proceed from the most downdrift groin in an updrift direction. If the sequence of construction is reversed, the groin farthest downdrift will take a long time to fill because each of the updrift compartments must fill before sand will start to bypass to the next downdrift compartment.

(4) If a groin field is to be constructed, monitoring the filling rate of the first groin during construction can provide timely transport rate data for comparison with transport rates adopted for design. The observed rate might then be used to modify or revise the construction schedule of subsequent groins. The designer is cautioned here, however, about using short-term data without some evidence of its applicability.

(5) Observations of the performance of existing nearby groins of a similar type of construction will indicate if rip currents will form along the proposed groins.

(6) Some indication of a groin's structural performance can also be obtained by noting the condition of nearby groins. Nearby groins, if they terminate offshore in the same depth of water, will be subjected to the same wave environment and thus to approximately the same wave forces. Structural damage to existing groins can be used as an indicator of the wave environment. The armor stone size of a damaged rubble-mound groin can be determined and used to check the armor stone size of a proposed groin design. Similarly, undamaged rubble-mound groins can provide an upper limit on required armor stone size. The frequency at which existing groins sustain damage and their level of performance in a damaged state can help establish an acceptable level of design. (It may not be economical to design for a very large wave because it will rarely occur.)

(7) Information on the structural performance of other types of groins can also be obtained by observing the performance of existing structures. For example, some measure of the potential for structural deterioration, corrosion, abrasion, etc., can be obtained by noting the effects of these processes on nearby structures.

*b. Model Investigations.*

(1) Physical models.

(a) Physical models may be used for both functional and structural design of groins. Hydraulic model tests, their design, conduct, interpretation, etc., are presented in detail by Hudson et al. (1979). Additional information can be found in EM 1110-2-2904.

(b) For functional design, three-dimensional hydraulic models that include the effects of both waves and tides are generally required. A simple fixed-bed model can establish current patterns due to waves and tides; however, a tracer material (sand simulant) must be introduced into the model to model the effect of a project on the shoreline and on sedimentation patterns. Such fixed-bed models with sediment tracers have been used with moderate success to qualitatively (and to a very limited extent, quantitatively) describe shoreline evolution and define areas of scour and deposition. Model materials such as coal, walnut shells, and plastic beads have been used as tracers. Scaling laws and the relationship between time in the model and prototype are not precisely known. One difficulty is to accurately reproduce the prototype wave environment in the model; at best the model wave environment is simulated by a few different wave conditions that are assumed to characterize the prototype environment.

(c) Moveable bed models can be used to study groin behavior; however, in most cases, generalized research models rather than site-specific models have been used. Fine sand is often used as the moveable bed material; however, other materials have also been used. Often a distorted model, where the vertical scale is exaggerated, must be used. This usage further complicates the scaling laws needed to compare the model with the prototype. Moveable bed models are expensive to build and operate, and model results can be difficult to translate into prototype performance. In view of the limited quality of the information they provide, they are sometimes difficult to justify for projects involving groins.

(d) Physical models to study the structural performance of a groin's design may be justified where many similar rubble-mound groins are to be built or where the wave environment is particularly severe. Structural tests of groin types other than rubble-mound groins are not common. The wave and earth loading on sheet-pile groins is easier to define than the loading on and stability of rubble-mound groins. If stability testing is indicated, three-dimensional tests or tests in an L-shaped flume are necessary because waves usually approach a groin nearly head-on. It is usually the groin's head that must absorb the brunt of the wave attack, and it is the most critical element to be modeled. A model of the groin is built in an L-shaped or wide laboratory flume or basin and subjected to increasingly higher waves until armor units start being displaced by waves. The wave height that just initiates armor layer damage is established as the zero-damage wave height. A stability coefficient and a scaling relationship such as Hudson's equation are then used to determine the corresponding prototype armor unit size.

(2) Numerical models.

(a) Numerical computer models that model the effect of coastal structures on shorelines have evolved to the point where they can be used to predict the effect of groins and other coastal structures on a shoreline. One-line numerical models predict the location of a single contour line, usually the shoreline (LeMéhauté and Soldate 1980, Perlin and Dean 1979, Kraus 1983, Hanson and Kraus 1989). These models are the sediment budget equations applied to a finite difference representation of a stretch of shoreline. The equations express the conservation of sand with an equation of motion that relates sediment transport rates to incident wave conditions. For multiple-line models, onshore-offshore or crosshore transport is also considered. Onshore-offshore transport is related to wave conditions and to the local bottom slope. The incident wave conditions determine an equilibrium beach profile, and the existing profile moves toward that equilibrium. Wave conditions usually change before the equilibrium profile is reached so that the profile is continually adjusting toward a new equilibrium.

(b) Numerical models have the advantage of simulating shoreline response to time-varying wave conditions. The time-history of the shoreline, including its seasonal variations, can be computed if a time-history of the wave environment is available or can be synthesized. Wave data such as WIS hindcasts (Jensen 1983) can be used as input for such models. Numerical models also offer the potential of studying shoreline response to waves and water levels due to major storms (Larson et al. 1990).

(c) A one-line numerical model like GENESIS (Hanson and Kraus 1989) can be used to predict shoreline evolution following the construction of shore stabilization structures such as groins, offshore breakwaters, and seawalls. A description of GENESIS is provided in Appendix D.

*c. Empirical relationships.*

(1) There are few empirical relationships governing the design of groins and groin fields. For example, one simple empirical relationship is the recommendation that groin spacing be two to three times the groin length measured from the bermline to the seaward end of the groin.

(2) Another empirical rule deals with estimating the amount of sand bypassing a groin. For long, high groins that extend seaward to a depth of -3 meters or more below MLW or MLLW, all longshore transport is trapped. For high groins extending to depths of from -1.2 to -3.0 meters, about 75 percent of the longshore transport is trapped. Also, for low groins extending to less than -3.0 meters, 75 percent of the longshore transport is trapped. For high, short groins extending seaward to

depths of only -1.2 meters, 50 percent of the longshore transport is trapped. Note, however, that as a groin system fills, the water depth at the groin's seaward end changes so that the amount of sand bypassing the structure is a function of both time and incident wave conditions.